Vortex Generation Due to Coastal and Topographic Interactions and Numerical Studies of Internal Wave Dynamics

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LONG-TERM GOAL

Our basic goal is to achieve a better understanding of the turbulent flow of the oceans in terms of the laws that govern the behavior of vortices and waves and their interactions. Our program of research investigates how vortices and waves evolve and interact subject to oceanographically relevant forces. In particular, we are aiming at a better understanding of how internal wave energy propagates through the spectrum of physical scales and how it propagates from the deep ocean to the shallow coastal zones. Also we wish to understand the processes by which vortices and currents are generated in coastal regions.

OBJECTIVES

In our internal-wave project, we are trying produce a numerical simulation of the dynamical evolution of flow in the buoyancy range (roughly the 10m to 1m vertical wavelength spectral range). Full three-dimensional information about the structure in that range could help us understand better the observations of oceanic fine structure.

In our project on coastal interactions, the questions that we are trying to answer have to do with how the presence of a coast affects the basic processes involved in the evolution of vortices and currents. We wish to understand the role that coastal topography plays in permitting or inhibiting the bifurcations of coastal currents.

APPROACH

These investigations involve analytical, numerical and laboratory studies. In our coastal current investigations we have used spectral, finite difference and point vortex (particle-in-cell) methods to simulate dynamics near a coast. Transform methods have been used to provide analytic solutions in both quasi-geostrophic and shallow-water theory. Laboratory experiments have been performed with a rotating tank to verify the theoretical and numerical predictions. In our internal-wave investigations, we are performing simulations with both spectral and finite-difference three-dimensional simulation codes with subgrid scale models.

WORK COMPLETED

We performed a series of simulations of coastal flow over an escarpment aligned perpendicular to the coast . A paper on this work was published (Carnevale et al., 1999a). We performed a series of laboratory experiments in a rotating tank in collaboration with G-J. van Heijst and L. Sanson (University of Utrecht). These experiments confirm the numerical and analytical results.

For the study of stratified turbulence, we completed a series of numerical experiments in which various numerical schemes were tested. The subgrid scale parameterizations used in these schemes permits simulation of fine scale motions from the range of tens of meters down into the inertial range. We explored the use of continually –forced large-scale (Garret-Munk range) internal waves to drive the motions in the buoyancy range.

RESULTS

For the problem of coastal flow over an escarpment, we found very different results in two seemingly very similar geometries. If, when looking from deep to shallow fluid, the coast is found on the right (left), we refer to this as the right-handed (left-handed) geometry. Our theoretical and numerical results suggested that a coastal current encountering an escarpment in the right-handed geometry would bifurcate with part of the current flowing out from the coast along the escarpment, and the rest following the coast. In the left-handed geometry, repeated dipole production should be expected with the eddies propagating away from the escarpment and the coast, on the upstream side of the escarpment, with no outward flow along the escarpment, but with the entrainment of fluid from over the escarpment producing an inshore flow. This has been verified in the laboratory experiments (see figure 1).

In our numerical simulations of stratified turbulence, we have forced the flow by causing the internal modes with longest wavelength to evolve as if they were purely linear internal waves. This generates a cascade of energy to small scales that fills out the kinetic and potential energy spectra. Using this method, we were able to produce spectra in which there is a clear spectral break between the buoyancy range and the inertial range. Such a break is observed when there is a large scale breaking event in the flow. Such a breaking event is shown in figure 2.

IMPACT/APPLICATION

Our results on coastal current bifurcations may be useful in analyzing the flow in a variety of places where strong topographic variations occur in the along-shore direction. In particular, the flow along the steep side of the Jabuka pit in the Adriatic seems to be a good example of the flow we predicted for the right handed geometry. We have compared the trajectories of drifter tracks (Poullain,1997) and found that many line up with the steep gradient of the northeastern edge of the pit indicating a current very much as our results predicted.

It is rather difficult to reconstruct the flow structures in any given volume of the ocean from available observational data. For example, various explanations may be offered to explain a particular overturning event seen in a density profile. By observing similar events in a fully three dimensional data set produced by our simulations, we hope to be able to decide on the validity of various hypotheses currently used to explain the occurrence of such events. We have observed strong mixing events in regions of high strain and this may be related to the observations of Alford and Pinkel (1999: unpublished manuscript).

RELATED PROJECTS

In additions our papers mentioned above, there were several others published or submitted. In Kloosterziel and Carnevale (1999) we presented a new model of vortex stability including nonlinear saturation. In Orlandi and Carnevale (1999a), we explored the stability of vortices including the effect of the bottom Ekman layer. In Orlandi et al. (1998, 1999c), we considered the effects of density modulation on trailing vortices. In Carnevale et al. (1999b), we presented an analytical criterion for the suitability of various kinds of boundary conditions in general circulation models. Our work on internal waves involves comparisons between the data generated in our simulations with actual oceanic observations being made in two separate projects headed by M. Hendershott and R. Pinkel (SIO). We are collaborating with R. Kloosterziel (U. Hawaii) on internal wave packet propagation.

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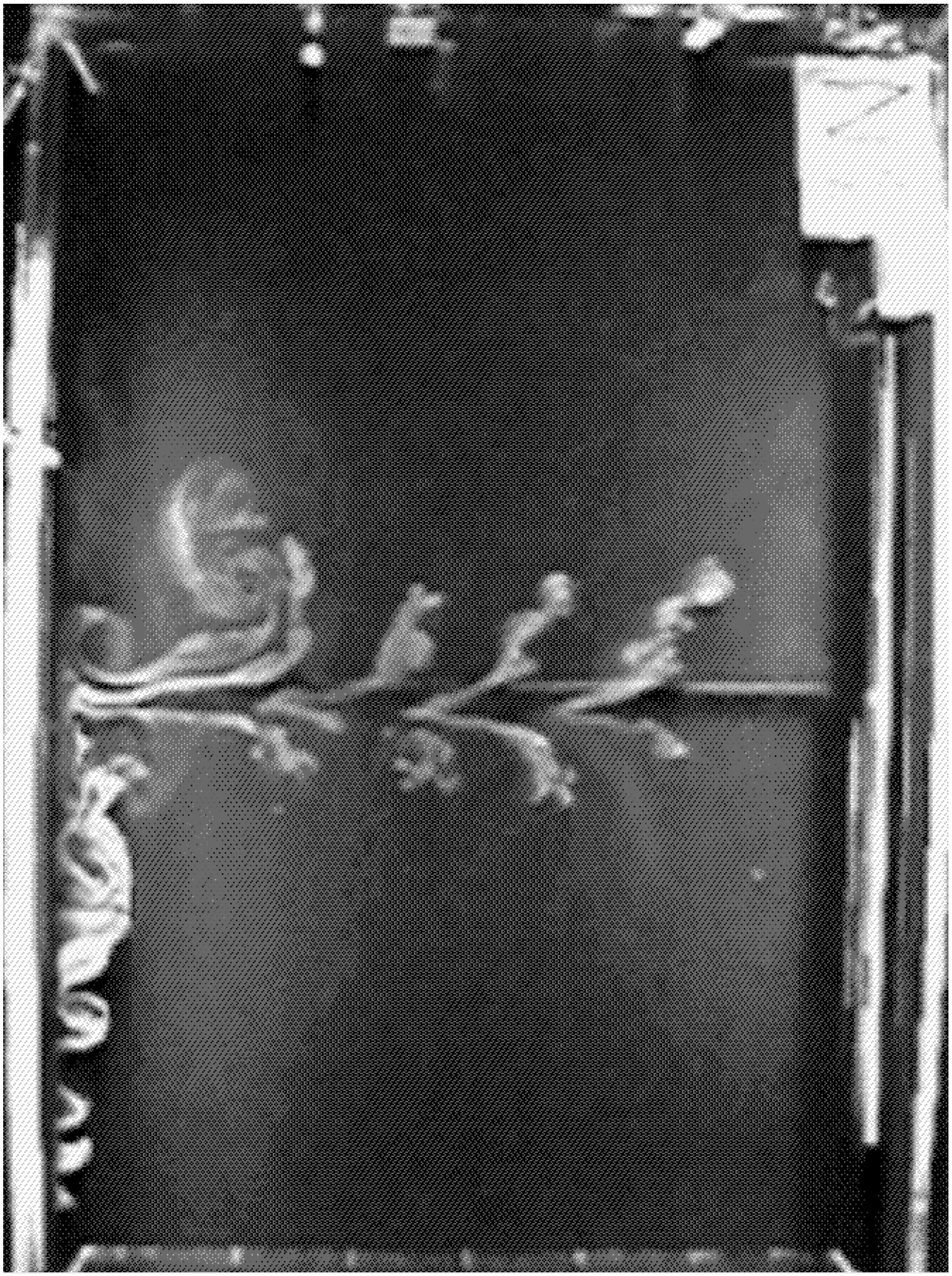

***Figure 1.** Photograph of dye concentration in rotating tank experiment viewed from above along the axis of rotation. The source of the boundary current is on the upper part of the left-hand wall. The current flows down along the left-hand wall until it hits the topographic slope (seen here as a horizontal line dividing the tank in two). There it bifurcates with part of the current following the wall. The other part repeatedly generates dipoles that leave the topography at an angle. At the same time an inshore current (i.e. a flow toward the left) is formed over the topographic slope.*

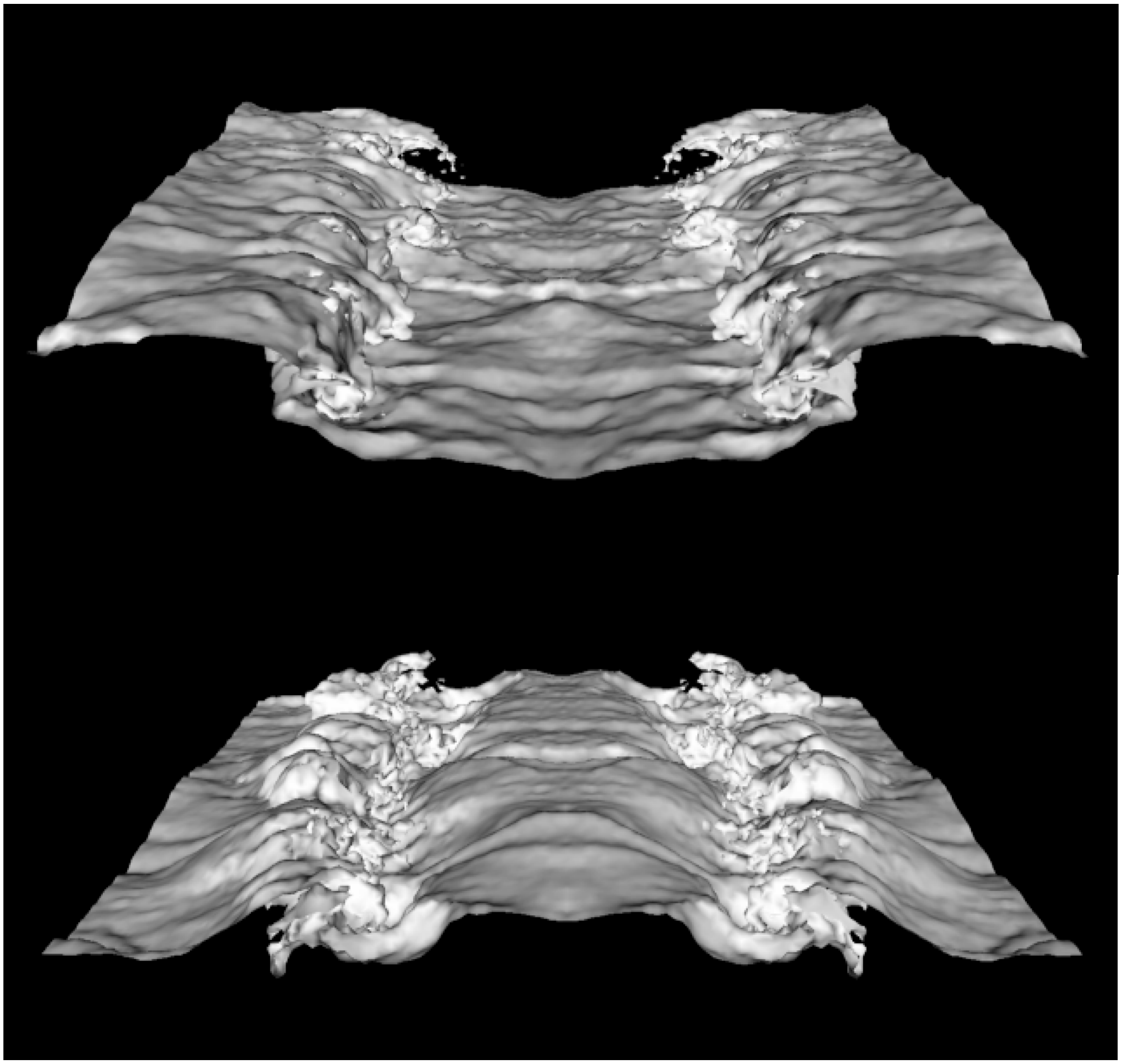

Figure 2. A wave breaking event forced by a large scale (20 m) standing internal wave. These images are the same density isosurface but at two different times separated in time by 1/7 of period of the large-scale standing internal-wave. There are two breaking regions on each surface because of the symmetry of the standing wave about the central axis of the figure. The computational domain is a cube, 20 m on a side.